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Daniel Amariei, Gilbert-Rainer Gillich, Ionel Negru

Researches Regarding the Effect of Nitinol Vibration Damper Applied to Infrastructures

Many of the performed researches all around the world aim to develop advanced technologies in order to enhance the performances of the infrastructure systems, different from the actual ones, fact which involves multidisciplinary research (IT, sensoring, electronics, smart materials and others), aiming to assist engineers in realizing full benefits of structural health monitoring. The paper presents a preliminary feasibility study of a system that can be used for damping of structural vibrations. Thus, shape memory alloys (SMA) components can affect through two mechanisms the structure's vibrations. The stresses from a SMA element that realize phase transformations, as a result of vibrations, have an effect on the frequency-amplitude characteristics. In addition, a dissipation of energy due to hysteresis in a SMA element can reduce the natural frequency and affect forced vibrations.

Keywords: *vibration, dampers, shape memory alloys, infrastructures, frequency*

1. Introduction

An efficient infrastructure system is essential to every country's productivity, security, and quality of life, the support for sustainable development that preserves and promotes opportunities for economic growth smart structures technology, offering tremendous opportunities to improve the performance, quality and environmental impact of products in many industrial sectors. New construction or the intelligent renewal of ageing and deteriorating civil infrastructure systems include efficient and innovative use of high-performance and smart materials, sensors and actuators, along with intelligent mechanical and structural systems.

The smooth functioning of a modern large city depends on the reliability of many inter-linked systems which all have to be designed, constructed, monitored and maintained over a long period of time. Among these systems is the large number of structures, including buildings and bridges, which often comprise the major part of the infrastructure investment. The present paper presents a solution regarding the development of a new generation system for infrastructures, consisting in the use of Shape Memory Alloys for designing an Intelligent Vibration Control System IVCS.

SMA is a term used for a group of metals that exhibit the ability to return to a previously defined shape by increasing the temperature. The mechanical behaviour of SMA can be divided into two categories: the shape memory effect (SME) and superelastic or pseudoelastic effect. SME refers to the ability of the material to recover large amounts of residual strain, caused by loading and unloading, upon raising the temperature of the material. Pseudoelastic effect refers to the ability of the material to achieve a very large strain upon loading that is fully recovered through a hysteresis loop upon unloading. This unique ability to fully recover large strains (as high as 10%) is a result of martensite phase transformation occurring in the SMA material according to certain environmental and boundary conditions.

Applying these future solutions, the infrastructure systems will not only last longer but will have far lower maintenance demands. They will be able to be modified to accommodate changes in exploitation or function more quickly and in a far less intrusive manner than current technology allows.

2. Analysis.

The key challenge of this solution is to bring the current fundamental breakthroughs on the level of materials, IT, electronics and control to the level of industrial use in integrated applications.

To be able to achieve this, the smart systems should not any longer be considered as a product add-on. The material and smart system design process must become part of the complete, integrated, product creation process, requiring the development of an adapted simulation-based Computer Aided Engineering methodology.

The core idea is to develop such modelling framework for designing macro-scale active noise and vibration control applications based on the integration of intelligent, high-performing, material systems. This requires the development of modelling capabilities for the intelligent material systems and sensor / actuator components, for the control systems as well as for their integration in system-level virtual prototyping models, enabling the evaluation of performance as well as reliability and cost aspects.

Making this next step in smart systems goes beyond the technological developments. The key requirement is that the various domain specialists on the level of materials, electronics, control systems, design simulation, dynamics, noise, vibration etc, step outside their niche expertise domain and get fully acquainted with the multidisciplinary aspects related to the integration of all these components in industrial applications. Without this, smart structures will remain an academic topic. As such integrated knowledge is at present not available with product and subsystem designers; a multidisciplinary training program is needed and will be developed.

3. Experimental results.

The performed research intents to be used as a preliminary feasibility study for a project idea, regarding SMA passive diagonal bracings for vibration suppression applied to infrastructures.

Constitutive behaviour of SMA wires used in the study was experimentally characterized to properly model the SMA pseudoelastic material properties and results were compared with the numerical simulation based on theoretical SMA constitutive models by Lexcellent and Bourbon ((1996).

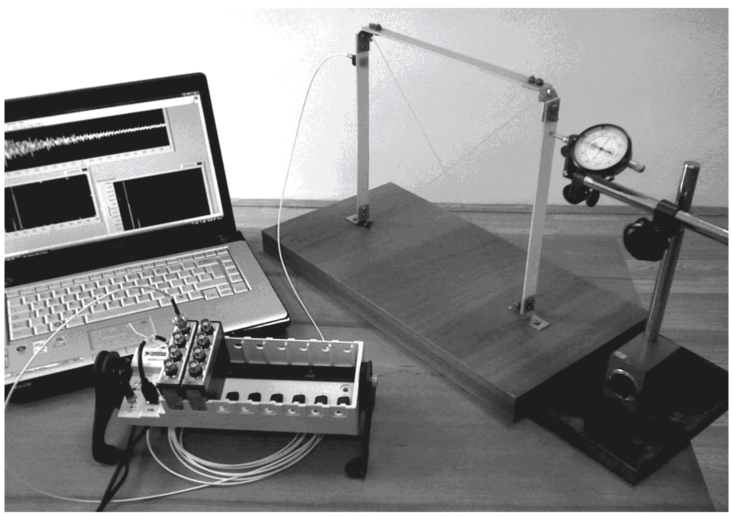

Figure 1. The experimental stand with a single degree of freedom

A single-degree-of-freedom structural frame, made of glass-fibber strips, having as diagonal bracings Nitinol wires of 0,250 mm diameter, along with a laptop, a NI cDAQ-9172 compact chassis with NI 9234 modules and a Kistler 8772 accelerometer, used to acquire the signals, was experimentally calibrated to determine the structural parameters. Both the experimentally calibrated structural model and SMA constitutive model were then employed in numerical simulation to predict dynamic response of the building structure with SMA bracing wires subjected to a base input and results showed a good agreement with experimental data. The results were also compared with both cases of one bracing wire and no bracing at all.

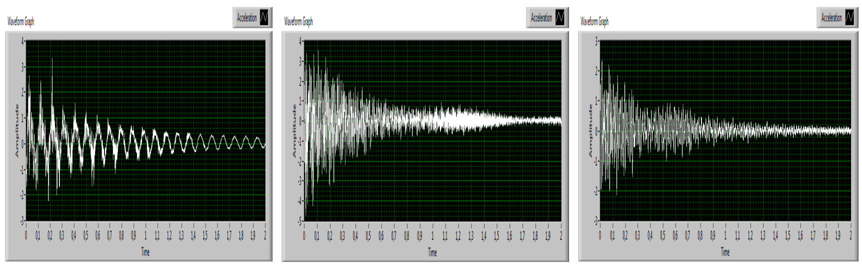

Figure 2. The three experimental phases acquired signals used for calibration

The results showed that SMA passive devices may be effectively have real effect for vibration suppression by introducing additional stiffness to shift the system natural frequency away from the resonance, providing additional energy dissipation by its superelastic hysteresis. The SMA damping is adaptive and is especially attractive for the case when the loading is random in nature. When an unexpected excitation causes excessive vibration, more energy will be dissipated through larger SMA superelastic hysteretic loops and therefore, the vibration will eventually be mitigated.

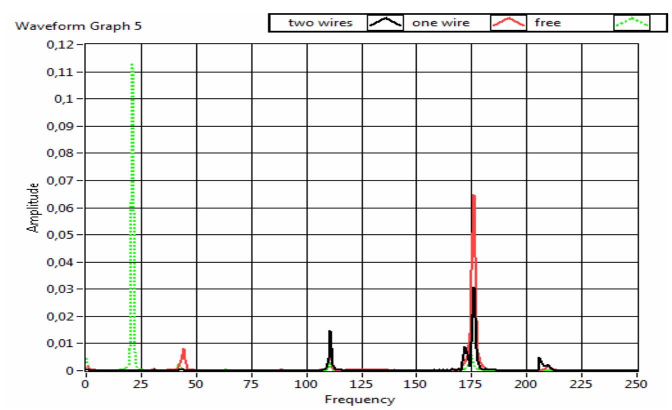

Figure 3. Comparison between the system natural frequency

The tension force in one of the SMA wire that was calculated from the response and the excitation based on the following expression:

$$F_{SMA} = -m(\ddot{x} + \ddot{z}) - c\dot{x} - kx, \quad (1)$$

where x is the system displacement, $\dot{x}$ is the system velocity and $\ddot{x}$ is the system acceleration.

The obtained acceleration signal from the experiment was integrated in order to get the displacement and velocity data necessary to obtain the experimental SMA force from equation 1. The results used top excitation amplitude of 3.2 mm.

Figure 3 presents a response spectral graphical comparison of the structural system natural frequency for the three studied cases (without any bracing, then with one and two SMA bracing wires).

It was easily observed that both one and two SMA bracing systems could be effectively used to suppress structural vibration, especially in the frequency range near the resonance, due to the fact that both introduce additional stiffness into the system, shifting the system away from its original resonance range. Also, the spectrum for the SMA bracing has the smallest peak value mainly due to the adaptive damping provided by the SMA superelastic hysteresis. The greater the amplitude leads to more energy dissipation, which results in smaller peak response.

4. Conclusion

As conclusions drawn from this study, we could mention that the SMA bracing system used in this study were effectively used to suppress vibration by introducing additional stiffness to shift the system natural frequency away from the resonance, providing additional energy dissipation by its superelastic hysteresis effect, supporting in this way reasonable and practical sustainable development initiatives which offer real solutions for the growing infrastructure needs, economic growth in communities and promote a greater quality of life.

The SMA damping is adaptive in the sense that more energy will be dissipated through its superelastic hysteresis as the response amplitude increases. The adaptive SMA damping is especially attractive for the case when the loading is random in nature. When an unexpected excitation causes excessive vibration, more energy will be dissipated and the vibration will eventually be mitigated. Therefore, the SMA devices may have certain merits over the traditional passive vibration control devices such as energy absorbers and base isolators.

Both Brinson and Lexcellent SMA constitutive models can be well employed in predicting dynamic behaviour of SMA passive devices after appropriate calibration using experimental data. It is expected that a SMA passive device generally becomes more effective if a larger deformation of the SMA material occurs.

Is important to mention that in this report the SMA was compared to the damping of the structure and not with other dampers that are well known to be effective.

Many important issues should be investigated in the future such as scaling effects, a comparison of the SMA passive device with different dampers, a study of the manufacturing and impact on the cost of the SMA device, and the impact of implementing the SMA devices in a multiple degree of freedom system

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Addresses:

- PhD Stud. Eng. Daniel Amariei, "Eftimie Murgu" University of Reşiţa - CARDT, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, d.amariei@uem.ro
- Prof. Dr. Eng. Ec. Gilbert Rainer Gillich, "Eftimie Murgu" University of Reşiţa - CARDT, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, gr.gillich@uem.ro
- PhD Stud. Eng. Ionel Negru, "Eftimie Murgu" University of Reşiţa - CARDT, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, negru_ionica@yahoo.com